# COMPARATIVE DYNAMIC PILE TESTING IN BELGIUM.

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### 1. Introduction.

A pile loading test allows either to determine the optimal characteristics of piles (sections, depth, ultimate and working loads) before installation (design), or to control the bearing capacity after installation. Until about 15 years ago, this experimental determination was only reached by means of static testing. Since then, pile dynamic testing has became more and more popular in the deep foundation community because of the many advantages offered by its two main fields of application: integrity testing and dynamic load testing. However, if considerable progress has been obtained in the theory, in particular in the field of mathematical models, its application in foundation engineering has not been solved completely yet and there is still more knowledge to be gained by experimental tests in particular in the comparison of "static" resistance and dynamic resistance.

One of the aims of the full scale tests on the site of Ghent (Belgium) is to fill in a part of this hiatus, the other aim being a better knowledge of the behaviour of screwed cast-in-place concrete piles, for which it is necessary to reconsider the actual design methods which do not seem to consider completely the real conditions of installation. This research has been realized by th Belgian Building Research Institute (B.B.R.I.) with assistance of Belgian contractors specialized in installations of such piles and with financial support of the Belgian Institute for Scientific Research in Industry and Agriculture (I.R.S.I.A.-I.W.O.N.L.).

In order to optimize the experimental possibilities offered by this research, the Belgian Member Society of the I.S.S.M.F.E. has decided to organize a symposium on Pile Dynamic Testing, related to the tests realized at Ghent, allowing the concerned people to receive a quick feedback of the teachings of this research. Various organisations specialized in this field, coming from France, Germany, Luxemburg and Netherlands, were invited to actively participate in the tests.

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I. <sup>pile</sup> testing program.

1.1. Type of piles to be tested.

mere are two classes of cast-in-place screw piles: displacement screw piles and FUNDEX piles), and replacement screw piles pere alt ATLAS and FUNDEX piles), and replacement screw piles (e.g., piles bored (e.g., a continuous hollow auger):

,1,1, pisplacement screw piles (ATLAS, FUNDEX).

psplacement screw piles are installed by screwing a steel tube of which the pisplaces is provided with a stem auger whose diameter is wider than that of the The installation is achieved by means of a torque combined with a static not the axis. As soon as the required depth is reached, a reinforcement <sup>103d</sup> is introduced in the tube and the tube is filled up to the top of the uper tank with concrete of high workability.

the ATLAS piles, the lower, smaller part of the screw tip remains in place, while the tube and the widest part of the screw tip are extracted by reverse screwing. By withdrawing the tube faster or at the same speed as the screwing speed, it is possible to obtain variable thickness of the concrete wir cast around the concrete shaft, depending of the soil conditions.

for the FUNDEX pile, the screw shoe remains completely in place while the tube sextracted with an alternatingly upward and downward movement; so one stains a pile whose diameter of the toe, which is equal to the wider part of the screw, is greater than the one of the shaft whose lateral surface is rather regular.

2.1.2. Replacement screw piles.

mese piles are driven into the ground by screwing down to the required depth, continuous flight auger with a hollow shaft provided with a loose cap. The riving is achieved by means of a torque combined with a static load on the mis. During screwing, a part of the soil is transported in upward direction ud forms a cone at ground level around the continuous flight auger. Then concrete with a suitable composition and workability is pumped under high messure without interruption via the hollow shaft of the auger.

It is mainly the concrete pressure at the bottom of the auger which has to ince the auger out of the ground. One can make it easier by means of a light alling on the top of the auger, without rotation. After extraction of the uger, a reinforcement cage can be introduced in the fresh concrete by means of a vibrator.

# 1.2. Test program.

five piles, each of type previously described, were installed in a rather andy ground. Five concrete precast piles without enlarged base were also "iven in order to have a good reference.

Thus, a total of 20 test piles were installed as shown on Fig.1, following Thus, a total of 20 test piles were installed as presented has been idential raster of 5 by 5 m. For each type, the order of execution has been idential top of the top of top of the top of top of the top of to raster of 5 by 5 m. For each type, the order of calculation  $t_{\rm calculation}$  in order to obtain test conditions as similar as possible. The top of  $t_{\rm calculation}$  in order to obtain test conditions of test to be carried out on it:



-a first pile was installed in order to allow the pilecompany to adjust its production procedure (Row e

-a second pile was to be tested for integrity (Row d, Piles 16 to 19).

-a third pile was formed to support a dynamic loading test following the procedure which is described in section 3.2 (Row c, Piles 12 to 15).

-the last two piles were formed in order to be tested statically up to the ultimate load, which is the load to apply in order to obtain a movement of the toe of at least 10% of the diameter or side of this toe (Rows a and b, Piles ) and 5 to 11).

Cast in situ piles: (FUNDEX, CONTINUOUS AUGER, ATLAS)

> $\Box$ Precast concrete pile

CPT-test with S-M4 cone 1

- V CPT-test with S-E cone
- Boring +undisturbed samples + SPT-tests  $\bigcirc$
- O Pressuremeter test.

The static loading tests were executed on piles other than those to be tested dynamically, in order to avoid one type of test to influence the results of an other one. A rather homogeneous sub-soil condition was proved by CPT-tests executed at the place of each future pile. This allows to consider the results as representative for all the site.

The reaction points needed for the execution of the static loading tests are obtained for each pile to be tested by means of two cast-in-place driven piles (FRANKI); these piles were driven before execution of the screw piles, at a distance of 2.5 m from each side of the screw piles (Fig.1, Piles A to L).

1.3. Site investigations.

test site was choosen after a preliminary documentary study (geological ne geotechnical maps, CPT-tests previously executed in the neighbourhood).

detailed site investigation performed comprised:

<sup>26</sup> CPT (19 with a cone type S-M4, 7 with a cone type S-E): 3 preliminary to confirm the choice, 12 tests at the place of the future piles to be statically or dynamically and 8 tests performed later, just near some ested statically or dynamically and 8 tests performed later, just near some iready executed piles in order to verify how their execution can modify the iready characteristics and finally 3 complementary tests with a continuous soil characteristics and pore pressure.



FIGURE 2. - TYPICAL RESULTS OF SITE INVESTIGATION. -1 boring with undisturbed samples taken from various depth for complementary laboratoy test and with execution of SPT-tests at some levels compatible with the abovementionned samplings.

-1 boring with execution of standard pressuremeter tests every meter.

-4 static loading test (until 400 kN) by means of a large plate of  $\phi$  3.20m (maximum pressure of about 0.05 MPa).

Fig.2 gives the results of tipical investigations obtained on site: one CPT-test, the pressuremeter tests, the values of SPT-tests.

2.4. Preliminary design of the piles.

The different pile-companies determined, prior to the installation of the piles, the dimensions and the ultimate load of their piles; this design was based on each CPT-test performed at the place of each of the test piles to be installed. Three design criteria were imposed:

-the toe was to be situated between 12 and 15 m beneath the ground level;

-the ultimate load at the pile toe,  $Q_P$  ,calculated with  $q_c$  from the CPT-test had to be constant at about 2 m beneath the toe level;

-the mean constraint in the concrete of the shaft had to lay between 15 and 20 MPa under a maximum load of 2 MN.

The so determined characteristics are given in Table 1 where one can also the limit load given for a measured movement of 2.5 % of the diameter or side of the pile.

## TABLE 1: FORESEEN CHARACTERISTICS FOR THE TESTS PILES AND MEASURED LIMIT LOAD IN MN

PILE TYPE	SECTI ø or	ON (m) side	PILE N <sup>r</sup>	LENGTH (m)	FORESEEN Qp	LIMIT Qs	LOADS Q1 p	MEASURED LIMIT LOAD (*)
PRECAST	square	shaft	7	13.90	1.087	0.890	1.977	NA
	0.3	2*0.32	11	13.30	1.053	0.959	2.012	2.800
	toe: i	d.	15	13.40	1.103	0.896	1.999	-
ATLAS	shaft:m	in:0.36	6	12.50	1.223	0.653	1.881	2,012
	m	ax:0.46	10	12.50	1.141	0.784	1.925	2.022
	toe:	0.46	14	13.00	1.223	0.733	1.956	-
CONT.	shaft	0.45	5	14.50	1.242	0.247	1.489	1.720
AUGER	toe:	0.45	9	14.50	1.153	0.303	1.455	1.620
			13	14.50	1.285	0.333	1.617	-
FUNDEX	shaft:	0.38	3	13.00	1.638	0.400	2.038	2.040
	toe:	0.45	8	13.00	1.527	0.412	1.939	1.860
			12	13.00	1.694	0.364	2.058	-

(\*) See section 3.4.

2.5. Organisation of the research.

The research has been realized in 1987 in the following order:

- site investigation (March),

- driving of the 12 tension FRANKI piles (6th-10th of April),

- screwing of the 5 FUNDEX test piles (23th of April),

- screwing of the 5 ATLAS test piles (24th of April),

- boring of the 5 continuous auger piles by SOCOFONDA (8th of May),

- driving of the 5 precast concrete piles by DE WAAL (15th of May),

- integrity testing campaign by organisations coming from different European countries ( $25^{th}$  of May; participants: BBRI (B), CEBTP (F), FRANKI (B), FUGRO (NL), MAGNEL (B), TNO (NL)),

- 4 dynamic loading tests by different organisations on May  $26^{\,t\,h}$  and  $27^{th}$  (see section 3.1),

- 8 static loading tests and complementary site investigations ( $26^{th}$  of Juni until  $18^{th}$  of July),

- complete extraction of 3 piles (Pile 12 FUNDEX, Pile 13 SOCOFONDA, Pile 19 DE WAAL) and partial extraction of ATLAS Piles 14 and 18) from the  $5^{18}$  to the  $9^{1h}$  of October).

1.6. Results of the static loading tests.

static loading tests were executed following a procedure allowing to static loading tests were executed following a procedure allowing to a separate measure of shaft and toe resistances. The pile was statiitain loaded by successive steps of constant load up to the ultimate load. ull each load step of about 15%, 30% and 70% of the estimated ultimate load, if er was completely unloaded. be pile was completely unloaded.

<sup>11g.3</sup> gives the load-movement curves for all of the tested piles (except Pile <sup>11g.3</sup> which the results are not available). The load-movement curves were <sup>1 for</sup> the influence of movements caused by the respective unloading <sup>ofrected</sup> for steps.





The duration of the loading steps has always been equal to 60 minutes, except for the two first steps of each test where one choose 30 minutes, and for the last step where the duration was determined by the time after which it wasn't my more possible to maintain the load more or less constant. In every case the movement used for the diagrams and in the following discussion is the settelement extrapolated to 60 minutes.

J. Belgian symposium on pile dynamic testing.

# 3.1. Case studies

In order to give a very concrete impetus to the Belgian Symposium on Pile Bynamic Testing, the Organizing Committee has taken the challenge to focus one full day of the Symposium on case studies offered by the B.B.R.I. site. Case Study I was dedicated to integrity tests.

Case Study II was dedicated to the challenge of a Class-A prediction: loading tests were executed on 4 different pile types (May 26<sup>th</sup> to 27<sup>th</sup>); the results of measurements were collected on site and a final report was to have made available 4 weeks after testing (22nd of June 87), i.e., before any static loading test had begun.

The organizations who took part in the exercise were : BALKEN PILING SYSTEM (S), C.E.B.T.P. (F), FRANKI s.a. (B), L.C.P.C. (F) and T.N.O. (NL). An independent "Evaluation Committee" was appointed in order to collect reports and prepare a synthesis of these, including the results of the static loading ten made available in September 1987. The reports submitted to the Evaluation Committee have been published in extenso in the Proceedings of the Symposium The salient features of this exercise are summarized in the following paragraphs.

# 3.2. Loading Procedure

The 3 cast-in-situ piles were provided with a quick setting concrete head. All participants fixed their instrumentation on this well defined cylinder (diameter = 0.4 m, h = 1.5 m). The prefab pile had a stick-up of 1.4 m and required no special preparation. The loading system supplied by FRANKI consisted of a guiding tube, centered on the pile head with the help of a crane and held in place by 8 big bolts. The 40 kN hammer was designed to slide freely in the guiding tube and hit a cushion on the pile head. The cushion was designed to allow a high energy level to be delivered to the pile without damaging it. The maximum drop height allowed by this system was 2.0 m.

The piles that were dynamically tested (Row c, Fig.1) were loacated 5 or 10  $_{\rm H}$  away from the piles which were later statically tested (Rows a and b):

Pile 12 : Fundex pile,

Pile 13 : Continuous auger pile installed by Socofonda,

Pile 14 : Atlas pile,

Pile 15 : Prefab pile installed by De Waal.

The complete testing of each pile took half a day, to allow for coordination during testing and for shifting the instrumentation. The loading procedure which was followed for each of the 4 piles was:

- drop the hammer from 0.2 m a couple of times to allow every participant to check his instrumentation,

- deliver a series of blows of increasing energy, the step increment of the drop height being 0.2 m and the maximum drop height being typically 1.2 to 1.6 m,

- when the agreed allowable stress on the concrete was reached, then deliver a series of blows of decreasing energy.

Some blows were repeated to make sure that all participants had their own valid record of the same event.

# collected information

the end of each day, the evaluation committee collected copies of the the signals. It was asked that the final report should include a desof the interpretation method and a summary of the results of the reption each pile. Particulary relevant information invited was: the bearing ists for with its definition (criterion), the toe resistance and the shaft apacity distribution and preferably, a prediction of the load-movement istance

reports from CEBTP, FRANKI and TNO reached the Evaluation Committee on the Late reports were however encouraged after providing the participants the additional information concerning the length of the piles: BALKEN turned with additional in late August, and LCPC theirs in late September 87.

p spite of the differences between the models used by the various particisome similar items were supplied; the "resistances" along the shaft and the toe were provided by FRANKI, TNO, BALKEN an LCPC; the prediction of the top or the curves was provided by CEBTP, FRANKI and BALKEN.

1.4. Comparison of predictions with static loading tests

indicated in section 2.2., the many CPT-tests carried out at the location of each tested pile confirmed that the ground conditions prevailing for the dynamically loaded piles were virtually identical to those prevailing for the statically loaded piles.

pecause it is not always clear from the specialists reports whether the "resistances" are to be understood as mobilized or ultimate, or to which settlement they correspond, the best picture that can be given to compare the oredictions is the load-movement diagram or data derived therefrom.

This is why the predicted load-movement diagrams are compared in Fig. 4 (precast pile), in Fig. 5 (ATLAS pile), in Fig. 6 (continuous auger pile) and in Fig. 7 (FUNDEX pile).

On these diagrams, the limit load  $Q_1$  is defined (recommandations of CNP 5, 1984) as the load corresponding to the movement,  $s_1$ , given by:

 $s_1 = 0.025 b + M Q_1$  (1)

where b is the base diameter and M the compliance of the pile.

Table 2 compares the essential design features of the piles: the limit load,  $Q_1$ , and the movements under a load of 1 MN and under 0.5  $Q_1$  (factor of safety of 2) and includes for each pile the numerical equivalent of eq. (1).





# TABLE 2: DESIGN FEATURES OF THE PILES.Q, Q1 in MN, s, s1 in mm

PILE TYPE	DESIGN DATA	PREDICTIONS piles from Row c (*) CEBTP FRANKI BALKEN	STATIC LOADING TESTS Piles from: (*) Row a Row b
PRECAST	Qı	≥2.80 2.06 ≥1.64	2.80 N.A.
S1 =	s (Q = 1)	2.2 3.4 4.0	3.0 _
9.0+2.5 Qi	s (Q = 1.38)	3.4 6.0 6.8	4.3 _
ATLAS	Qı	2.20 ≥2.60 ≥1.24	2.22 2.12
s <sub>1</sub> =	s (Q = 1)	4.0 2.8 5.6	4.0 4.0
10.0+2.8 Q1	s (Q = 1.09)	4.2 3.0 6.2	5.8 5.8
CONT. AUGER	Q1	1.26 1.66 ≥0.87	1.62 1.72
s1 =	s (Q = 1)	8.0 5.2 ?	5.2 4.6
11.3+2.0 Qı	s (Q = 0.84)	6.0 3.8 5.2	3.8 3.4
FUNDEX	Qı	1.90 2.60 ≥1.81	1.86 2.04
s1 =	s (Q = 1)	3.4 2.8 4.4	2.8 2.8
11.3+1.9 Qı			
(*) see loca	tion in Fig.1.		

Fig.8 shows the predicted movements,  $s_p$ , versus the measured movements,  $s_{s_1}$ , under the reference loads (1 MN and 0.5  $Q_1$ ). This figure includes the results available from the reports of CEBTP, FRANKI and BALKEN.



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# 1.5. Conclusions

The predicted movements under working load (Fig.8) are in rather good agreement with the measured ones, bearing in mind the usually high degree of uncertainty of this type of prediction. The predictions tend to be on the safe side, the average prediction,  $s^{av_p}$ , being 15 % overestimated:

 $s^{av_p} = 1.15 s_m$ 

The spread of the predictions can be contained within 2 lines going through the origin of the graph, defined by the equation :

 $s_p = s^{av_p} (1 \pm 0.4)$ 

We predicted limit loads  $Q_{1P}$  (cf. Fig.9) are also in rather good agreement with the measured,  $Q_{1m}$ , the average predictions being equal to the measurements. The spread of the few predictions available can also be contained by two lines going through the origin of the graph, defined by :

 $Q_{1p} = Q_{1m} (1 \pm 0.3)$ 

## 4. General conclusions.

The Belgian Symposium on Pile Dynamic Testing has offered a unique opportunit to assess the reliability of Class-A predictions, thanks to the BBRI reliable program with its four different types of piles.

The predictions given by those who felt they could indicate that dynamic ding tests lead to a fair assessment of the bearing features of piles:

- the movements under the working load were 15 % overestimated in  $av_{er_{a_1}}$  with a relative dispersion of 40 %,

- the limit load was correctly estimated in average, with a  $relati_{i_{i_j}}$ 

### 5. Summary.

In order to ascertain the validity of predictions of the bearing capacity of piles from dynamic testing, the Belgian Geotechnical Society has organized a workshop with various professional and research organizations knowledgeable in this field. Four piles types were dynamically tested : a prefab pile, a continuous auger cast pile, an Atlas pile and a Fundex pile. Five measuring teams recorded the same blows and presented to an independent Evaluation Conmittee their predictions of the bearing features of these four piles, within four weeks. Then only were two other piles of each type statically tested. Because of the good homogeneity of the sub-soil, the ground conditions prevailing for the two kinds of tests are virtually identical, allowing a comparison of the prediction and the measured load-movement curves. Conclusions are dom on the reliability of such predictions.

#### 6. References.

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